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SUBMISSION OF VERIFIED ENGLISH TRANSLATION OF  
PRIORITY DOCUMENT

Commissioner for Patents  
P.O. Box 1450  
Alexandria, VA 22313-1450

Sir:

In further response to the Office Action dated December 19, 2002, attached herewith is a verified English translation of priority document No. 99/02 126, in the above-identified application.

The USPTO is directed and authorized to charge all required fees, except for the Issue Fee and the Publication Fee, to Deposit Account No. 19-4880. Please also credit any overpayments to said Deposit Account.

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Date: April 28, 2004

I, Bernard Jean Lamoureux, residing at 24 place Duplex, 75015 Paris, France, hereby certify that I am conversant with the French language and am a competent translator thereof into the English language, and that to the best of my knowledge and belief the following is a true and correct translation of the specification and claims as originally filed on February 19, 1999 in respect of French patent application number 99/02 126.

Signed this 27<sup>th</sup> day of February 2004



A handwritten signature in black ink, appearing to be 'B. J. Lamoureux', is written over a horizontal dotted line.

## WDM REGENERATED TRANSMISSION SYSTEM

The present invention concerns wavelength-division multiplex fiber optic transmission systems and more particularly the regeneration of signals therein.

It is well known that to transmit optical signals over very long distances, as in the case of transoceanic transmission by submarine cable, it is necessary to amplify the optical signals periodically to compensate the attenuation of the signal and it is also necessary to reshape the signals to compensate distortion induced by the transmission medium or by interaction between the various signals of the multiplex. The distortion is compensated by regenerators whose functions include reshaping the pulses, retiming the pulses and compensating pulse intensity losses in the regenerator (regeneration termed "3R" for "reshaping", "retiming" and "reamplifying").

Wavelength-division multiplexed (WDM) transmission systems are tending to include more and more channels (or wavelengths) on each optical fiber. The bit rate per channel is also increasing. Thus the most recent transoceanic transmission systems have a capacity of 32 channels each of 10 Gbit/s.

There are various ways to regenerate the signals of each channel in such systems. One solution is to demultiplex the signals and to regenerate each signal individually. However, this solution has the disadvantage of requiring as many regenerators as there are multiplexed signals which, given the trend for the number of channels to increase, leads to a complex and physically large regenerator, also requiring a powerful electrical power supply, which represent heavy penalties in the case of transmission via submarine cable.

Another solution which can be used in the case of soliton WDM signals (or RZ signals converted into solitons at the regenerator input) consists in using a regenerator including means for compensating chromatic dispersion in order to resynchronize the various channels followed by a synchronous modulator. This solution has the disadvantage of requiring very accurate control of chromatic dispersion so that the signals are perfectly synchronized at the input of the synchronous modulator. Controlling the chromatic dispersion is all the more difficult in that it must be achieved for a large number of channels.

It has also been proposed, in the case of WDM soliton signals, to dispose the regenerators along the optical line at locations where a certain number of channels are naturally synchronous, and to regenerate only these channels at each of these locations (see WO-A-98 35459). However, this technique introduces a constraint on the position of the regenerators which can sometimes be problematical,

depending on the number of channels and their wavelength spacing.

The invention proposes a simple solution to the problem of regenerating channels in a WDM transmission system, and one which remains simple even if the number of channels is high.

To be more precise, the invention proposes a  $n$ -channels wavelength-division multiplex fiber optic transmission system including an optical transmitter and an optical receiver connected by an optical line including at least one optical fiber and at least one set of  $m$  ( $m > 1$ ) channel regenerating means, wherein  $p$  ( $p \leq m$ ) successive regenerating means regenerate respective groups of channels  $G_1, G_2, \dots, G_n$  forming a partition of the set of  $n$  channels.

The number of groups  $p$  is preferably a submultiple of the total number of regenerators  $m$  system.

The groups of channels preferably include a small number of channels, in particular a single channel or two channels.

This greatly simplifies the structure of the regenerator, compared to the solutions which demultiplex all the signals or compensate chromatic dispersion of all the signals with respect to each other.

Each regenerator advantageously includes an optical regenerator unit.

If a plurality of channels are regenerated in the same regenerator, each regenerator can include means for synchronizing the channels to be regenerated and an optical regenerating means, in particular a synchronous modulator.

In a first preferred embodiment of the invention each regenerator includes a demultiplexer and a multiplexer in order to process independently channels which are to be regenerated and channels which are not to be regenerated.

In a second preferred embodiment of the invention each regenerator includes an inserter/extractor system for isolating the channels which are to be regenerated.

A system in accordance with the invention can additionally include a compensator amplifier for compensating intensity differences between regenerated channels and non-regenerated channels.

The transmission system advantageously includes supervisory means using a dedicated channel. In a transmission system of the above kind, each regenerator can include means for separating the dedicated channel from the other channels, a supervisory unit for modifying the signal of the dedicated channel as a function of information relating to the status of the regenerator, and means for remultiplexing the dedicated channel with the other channels.

In particular, each regenerator can include a regenerating means for regenerating the channels of a group of channels, the supervisory unit receiving information from said regenerator unit and also receiving a fraction of the regenerated signal delivered by said regenerating means.

The system of the invention preferably includes a plurality of optical amplifiers separated from each other by a distance  $Z_a$  and optical regenerators separated from each other by a distance  $Z_r$ ,  $Z_r$  being a multiple of  $Z_a$ .

The features and advantages of the invention will emerge more clearly from the following description which is given with reference to the accompanying drawings and by way of illustrative and non-limiting example only, on which :

- figure 1 shows the general structure of a prior art optical transmission system including regenerators,

- figure 2 shows one embodiment of a regenerator in accordance with the invention,

- figure 3 shows a variant of the regenerator shown in figure 2 which is adapted to regenerate two channels,

- figure 4 shows another embodiment of a regenerator in accordance with the invention which is adapted to regenerate a single channel,

- figure 5 shows a variant of the regenerator shown in figure 4 which is adapted to regenerate two channels,

- figure 6 shows an optical transmission system in accordance with the invention equipped with optical supervisory means.

Figure 1 shows a conventional optical transmission system. It includes two terminal stations, namely a transmitter 2 and a receiver 4, connected by a fiber optic link 6. Amplifiers 8 are provided at regular intervals along the optical fiber to re-amplify the signals and so compensate losses due to absorption by the optical fiber. The distance  $Z_a$  between two successive amplifiers depends on many parameters (signal intensity, absorption by the optical fiber, wavelength separation between the signals, etc.); it is typically from 50 km to 100 km. The transmission system further includes optical regenerators 10. The distance  $Z_r$  between two successive regenerators also depends on many parameters (Kerr effect, Gordon-Haus jitter, four-wave interaction, etc.) which affect the shape of the pulses and induce an offset of the pulses relative to their nominal bit time. The regenerators are generally disposed at a distance  $Z_a$  relative to an amplifier 10 and include an amplifier similar to the amplifiers 8. The distance  $Z_r$  between two regenerators is equal to  $k.Z_a$ , where  $k$  is an integer generally from 5 to 10 and depending in particular on the bit rate of

the signals of the multiplex.

The invention differs from prior art transmission systems in that each regenerator regenerates a small number of channels. For example, for a WDM system with  $n$  wavelengths  $\lambda_1, \lambda_2, \dots, \lambda_n$  ( $n$  being equal to 32, for example), each regenerator could be designed to regenerate only one wavelength. In other words, the  $n$  channels could be divided into  $n$  groups  $G_1, G_2, \dots, G_n$  each including only one channel. There would then be in succession along the line, with intervals  $Z_r$  between each regenerator and the next, a regenerator  $R_1$  to regenerate the channel  $\lambda_1$ , a regenerator  $R_2$  for the channel  $\lambda_2$ , ..., a regenerator  $R_n$  for the channel  $\lambda_n$ , another regenerator  $R_1$  for the channel  $\lambda_1$ , etc. The important advantage is the simplification of the system by virtue of the fact that each regenerator has a simple structure.

Instead of a single channel per group, a transmission system can be provided in which the  $n$  channels are divided into  $n/2$  groups, each including two channels, and more generally a system in which the  $n$  channels are divided into  $p$  groups each including  $n/p$  channels.

Finally, the channels can be divided unequally between the groups, for example two channels in group  $G_1$ , three channels in group  $G_2$ , two channels in group  $G_3$ , etc.

The description with reference to the subsequent figures shows that each regenerator has exactly the same structure. This simplifies the design of the system and the manufacture of the regenerators, which increases the reliability of the transmission system.

For example, for a transoceanic link of 32 channels at 10 Gbit/s and having a length in the order of 10 000 km, the distance  $Z_a$  between amplifiers is in the order of 40 km and the distance  $Z_r$  between regenerators is in the order of 320 km.

Figure 2 shows a first embodiment of a regenerator designed to regenerate only one channel. It has at the input a duplexer 12 for separating the channel  $\lambda_k$  to be regenerated from the other channels  $\lambda_i$  ( $1 \leq i \leq n; i \neq k$ ) and at the output a duplexer 14 for remultiplexing the channel  $\lambda_k$  with the other channels. The regenerating means 16 can be of any type known in the art and advantageously includes a synchronous optical modulator in the case of soliton signals or RZ signals converted into solitons.

Generally, although optical regenerating means are currently preferred, the use of opto-electrical regenerating means, i.e. regenerating means in which the optical signals are converted into electrical signals, regenerated in electrical form and

then converted back into optical signals, is not excluded from the scope of the present invention.

The regenerating means are powered by an electrical cable 18 (not shown in figure 1). A compensator amplifier 20 in the branch of the regenerator receiving the non-regenerated channels compensates the intensity difference between the non-regenerated channels and the channel  $\lambda_k$ . In some embodiments, there could instead be a compensator amplifier of this kind in the branch receiving the regenerating means 16, should the latter induce an intensity loss in the channel  $\lambda_k$ .

When the regenerator 10 is at a distance  $Z_0$  from the preceding amplifier 8 (see figure 1), the regenerator 10 shown in figure 2 further includes an amplifier 8. This amplifier is preferably at the output of the regenerator 10, but could also be at its input. It could also replace the amplifier 20 shown in figure 2, in respect of the non-regenerated channels. In this case, the regenerating means 16 would have also to include an amplifier at the output of the regenerator 10 to amplify the signals to be regenerated to the same intensity as non-regenerated signals. The latter arrangement is particularly beneficial because the number of signals that each amplifier must amplify is then smaller, as compared to the line amplifiers 8 (figure 1). Amplifiers of lower power or a greater power margin can then be used in the regenerators.

Figure 3 shows an embodiment similar to that shown in figure 2, but adapted to regenerate two channels  $\lambda_k$  and  $\lambda_{k+1}$ . The only difference compared to the regenerator shown in figure 2 is the provision of synchronization means 22 upstream of the regenerating means 16 to synchronize the two channels to be regenerated. Synchronization means of this kind can simply be obtained, as shown here, with the aid of a three-port optical circulator 24 and a delay line 26 including two optical reflectors, for example Bragg filters 28, 30, spaced from each other so that the channels are resynchronized when they reach the regenerating means 16. The delay between the channels can be adjusted by means of a variable delay line 32.

Figure 4 shows a second embodiment of a regenerator designed to regenerate a single channel. It essentially includes an inserter/extractor system 33 which is a standard component in the field of optical transmission systems and a regenerating means 16. The inserter/extractor system 33 includes a first three-port optical circulator 34, a section 36 of optical line provided with an optical reflector 38, for example a Bragg filter, to reflect the channel  $\lambda_k$ , and a second optical circulator 40. These components are arranged, in a manner well known in the art, to extract the channel  $\lambda_k$  from the optical line and to direct it to the input of the regenerating

means 16 and to insert the regenerated channel  $\lambda_k$  received from the regenerating means 16 into the optical line.

It is important to note that the optical regenerator unit can be exactly the same for all the channels, for example in the case where the regenerator includes a synchronous modulator, with the result that the regenerator 10 can be adapted to any channel simply by choosing the wavelength to be reflected by the optical reflector 38. Thus the transmission system shown in figure 1 can be equipped with identical regenerators, which are "personalized" only in terms of the wavelength of the optical reflector 38, which simplifies manufacture, reduces costs and increases reliability.

The regenerator shown in figure 4 can be adapted, as shown in figure 5, to regenerate two channels  $\lambda_k$  and  $\lambda_{k+1}$ . This regenerator differs from that shown in figure 4 in that the line section 36 between the optical circulators 34 and 40 includes two optical reflectors for each channel. To be more precise, there are in succession on this line section: an optical reflector 42 for the channel  $\lambda_k$ , a variable delay line 44 and an optical reflector 46 for the channel  $\lambda_{k+1}$ , this combination forming resynchronization means similar to the resynchronization means 22 shown in figure 3, an optical reflector 48 for the channel  $\lambda_k$  and an optical reflector 50 for the channel  $\lambda_{k+1}$ .

The regenerator shown in figure 5 can be modified to regenerate more than two channels. Obviously, for this it is sufficient to add to the line section 36 optical reflectors adapted to reflect the channels to be regenerated and delay lines like the lines 44, if necessary.

Note that the compensator amplifier 20 of the regenerator shown in figure 2, intended to compensate an intensity difference between the channel or channels regenerated and non-regenerated channels, can be between the optical reflectors 46 and 48 in the case of the regenerator as shown in figure 5.

Over and above the structural simplicity of the transmission system in accordance with the invention, an additional advantage is the possibility of implementing a system element supervisory function in a simple manner. As is well known in the art, supervision consists in transmitting a signal over the line which is processed in each amplifier or regenerator to include therein information relating to the status, performance, etc. of the amplifiers and regenerators. This supervisory signal is on a specific channel in the bandwidth of the multiplex. The drawback of the prior art systems is that all the channels are regenerated simultaneously, which implies complex supervisory means in each regenerator (supervision of all WDM channels and associated synchronous modulators).



The transmission system in accordance with the invention has the advantage of enabling each regenerator to be supervised in a simpler manner.

Figure 6 shows a regenerator similar to that shown in figure 4, but with added supervisory means. The components identical to those in figure 4 carry the same reference numbers.

The supervisory means in the regenerator shown in figure 6 include: an optical reflector 52 for extracting and then inserting the supervisory channel  $\lambda_s$ , an optical coupler or demultiplexer 54 for separating the channels  $\lambda_k$  and  $\lambda_s$  extracted from the line by the circulator 34 and the reflectors 38, 52, an optical coupler or multiplexer 56 for remultiplexing the channels  $\lambda_k$  and  $\lambda_s$  after they have been processed, and a supervisory unit 58 for receiving information on the status of the regenerator 16 and on the status of the channel  $\lambda_k$  via an optical coupler 60 sampling a portion of the signal on the channel  $\lambda_k$  at the output of the regenerating means 16, the supervisory unit 58 transmitting that information on the channel  $\lambda_s$  to the optical coupler or multiplexer 56.

Supervision is simpler than in the prior art because it takes account of only a small number of channels of the multiplex at each regenerator (only one channel in the case of figure 4).

The invention is not limited to the embodiments described but to the contrary encompasses all variants that are within the scope of the following claims.

## CLAIMS

1. A n-channels wavelength-division multiplex fiber optic transmission system including an optical transmitter (2) and an optical receiver (4) connected by an optical line (6) including at least one optical fiber and at least one set of m ( $m > 1$ ) channel regenerators (10), wherein p ( $p \leq m$ ) successive regenerators (10) regenerate respective groups of channels  $G_1, G_2, \dots, G_n$  forming a partition of said set of n channels.
2. The system according to claim 1 wherein p is a submultiple of m.
3. The system according to claim 1 or 2 wherein each group  $G_1, G_2, \dots, G_n$  includes only one channel.
4. The system according to claim 3 wherein each regenerator is an optical regenerating means (16).
5. The system according to claim 1 or 2 wherein at least one group  $G_1, G_2, \dots, G_n$  includes two channels.
6. The system according to claim 4 wherein each regenerator for regenerating a plurality of channels includes means for synchronizing (22) the channels to be regenerated and an optical regenerating means (16).
7. The system according to claim 4 or 6 wherein each regenerator means (16) includes a synchronous modulator.
8. The system according to any one of claims 1 to 7 wherein each regenerator (10) includes a demultiplexer (12) and a multiplexer (14) to process independently channels which are to be regenerated and channels which are not to be regenerated.
9. The system according to any one of claims 1 to 4 wherein each regenerator (10) includes an inserter/extractor system for isolating channels to be regenerated.
10. The system according to any one of claims 1 to 9 wherein each regenerator includes a compensator amplifier (20) for compensating intensity differences between regenerated and non-regenerated channels.
11. The system according to any one of the preceding claims further including supervisory means using a dedicated channel  $\lambda_s$ .
12. The system according to claim 11 wherein each regenerator (10) includes means for separating (34, 52, 54) said channel  $\lambda_s$  from the other channels, a supervisory unit (58) for transmitting information relating to the status of said regenerator on said channel  $\lambda_s$  and means for remultiplexing (56, 40, 52) said channel  $\lambda_s$  with the other channels.

- 13.** The system according to claim 12 wherein each regenerator includes a regenerating means (16) for regenerating the channels of a group of channels and the supervisory unit receives information from said regenerating means and a portion of the regenerated signal delivered by said regenerating means (16).
- 14.** The system according to any one of the preceding claims further including a plurality of optical amplifiers separated from each other by a distance  $Z_a$  and a plurality of optical regenerators separated from each other by a distance  $Z_r$ , wherein  $Z_r$  is a multiple of  $Z_a$ .